MEMS Pirani Sensor for Pressure Measurements in the Fine- and High-Vacuum Range

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Abstract

For designing a MEMS type Pirani sensor a sophisticated analytical model was used [1]. Pirani sensors are based on a heating and sensing element or a combined element as in this case. We use a meander shaped resistor patterned onto a membrane, which is suspended by four 300 nm thin beams (see Fig. 1). On top of the chip rim we placed a radiation shield. The electrical heating power is dissipated by solid head conduction, gaseous heat conduction and by thermal radiation. Only the gaseous heat losses are pressure dependent. However, for some electrical configurations the working temperature of the heating element depends on the pressure in the system. Hence, the radiation losses vary with the pressure as well, because they strongly depend on the temperature difference between heated element and ambient. As it turned out, the analytical model did not show a sufficient precision in modeling the radiation in the system, so we switched to COMSOL Multiphysics® software for heat-flux analysis as it also includes radiation modeling features. Beside the heat losses, the geometric dependencies were simulated by parametric sweeps. The former prototype of the MEMS Pirani sensor is build up with exact geometries by using the CAD Import Module of COMSOL Multiphysics®. The important geometric aspect ratios, as membrane and beam shape and chip rim size are parameterized. Other geometries, like the etch groove and bridge length and width, are defined by calculation (relative variables). This way we are able to sweep the aspect ratios, so that we can approximate the gain in sensitivity related to the technological effort. The three heat losses are calculated by COMSOL Multiphysics® in the following way: solid as well as radiative heat transfer are simulated straight forward by the Heat Transfer Module. For the gaseous heat losses, we setup a geometric object filling the space between membrane and heat sink. This "solid" domain is configured to be transparent for thermal radiation and to have a pressure dependent thermal conductivity. The heating power dissipated in the membrane's resistor depends on its actual temperature. The signal-voltage response is calculated by transforming the T(p) results into U(p) by using analytic equations in the post-processing tools (Fig. 2). By sweeping geometric values, we can calculate a signal voltage response depending on the value of interest (see Fig. 3, radiation shields distance to membrane e.g.) for a specific pressure point. FEM tools are of great assistance in developing prototypes and analyzing their specific physical behavior. We are able to simulate the signal-voltage response of a high performance Pirani type vacuum sensor for its hole pressure range. The pressure dependent temperature distribution is transformed to the signal-voltage by using equations, which describe the electrical circuitry. The parameterization of the

geometric aspect ratios supports us in approximating the impact of a geometric value on the sensor performance.

Reference

F. Völklein, M. Grau et al., Optimized MEMS Pirani sensor with increased pressure measurement sensitivity in the fine and high vacuum regime, J. Vac. Sci. Technol. A, 31, 061604 (2013).

Figures used in the abstract

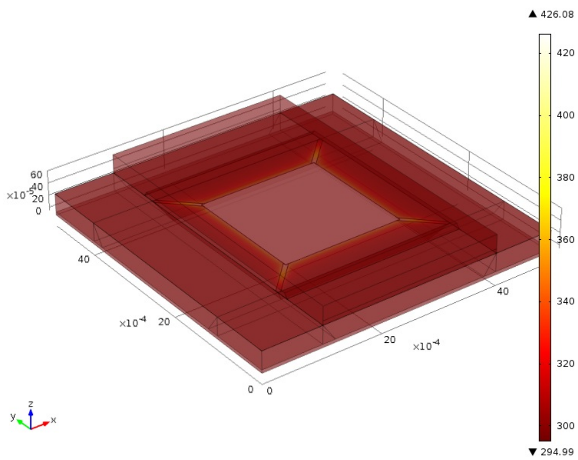

Figure 1

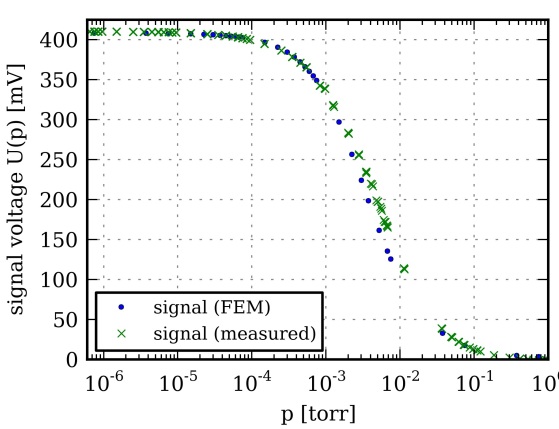

Figure 2

Figure 3